

Title: The crunch factor's role in golf-related low back pain

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## **Abstract**

**Background Context:** The golf swing exposes the spine to complex torsional, compressive and shearing loads, which increase a player's risk of injury. The crunch factor has been described as a measure to evaluate the risk of low back injuries in golfers and is based on the notion that lateral flexion and axial trunk rotation jointly contribute to spinal degeneration. However, few studies have evaluated the appropriateness of this measure in golfers with low back pain (LBP).

**Purpose:** To objectively examine the usefulness of the crunch factor as a measure for assessing the risk of low back injury in golfers.

**Study Design/Setting:** Field-based research employing a cross-sectional design.

**Methods:** This research used three-dimensional motion analysis to assess the golf swings of twelve golfers with LBP and fifteen asymptomatic controls. Three-dimensional kinematics were derived using Vicon Motus and the crunch factor was calculated as the instantaneous product of axial trunk rotation velocity and lateral trunk flexion angle.

**Results:** Maximum crunch factors and their timing were not significantly different between the symptomatic and asymptomatic groups. Furthermore, for those golfers who produced higher crunch factors (irrespective of group), the increased magnitude could not be attributed to an increased axial angular trunk velocity or lateral flexion angle, but rather to a concomitant increase in both of these variables.

**Conclusions:** The findings suggested that, while the fundamental concepts that underpin the crunch factor seem sensible, this measure does not appear to be sensitive enough to distinguish golfers with low back pain from asymptomatic players.

## Introduction

Over the past decade, golf has established itself as one of the most popular sports around the world, largely due to the fact that it poses no restrictions on gender or age and thus can be enjoyed late into one's lifetime [1-7]. However, despite the appeal of the game, several researchers have suggested that the increased popularity of golf combined with the common misconception that it is a risk-free sport, has effectively increased the prevalence of golf-related injuries [8-11]. Of these injuries, those to the lower back have consistently been reported to be the most common [12, 13], with incidences as high as 50% in the amateur and professional golfing populations [14]. According to Hosea and Gatt [15] and Armstrong [16], the majority of cases of golf-related low back pain (LBP) are caused by mechanical damage to the spinal column or associated structures. Furthermore, research suggests that up to 90% of low back injuries in the professional golfing population arise due to the repeated performance of the modern golf swing [17-23]. During a single practice session, it is not uncommon for golfers to perform this movement sequence over 300 times [24-26] and research demonstrates that golfers who have developed LBP tended to have practiced the full golf swing twice as often as their asymptomatic counterparts [27].

The repeated performance of the golf swing exposes the spine to a complex series of high-speed spinal loads, including axial torsional stresses, compression and shear forces [8, 15, 28-32]. Additionally, through the use of X-ray and CT scans, previous research has demonstrated asymmetric degenerative changes in the lumbar facet joints of professional golfers compared with non-golfer controls [33, 34]. According to Hosea and co-workers [21, 35] and Lim and Chow [36], peak compression, shear and torsional forces were achieved during the downswing and follow-through phases of the golf swing. The timing of these loads corresponds with anecdotal evidence, which suggested that up to 41% of low back

injuries are sustained during the downswing or at impact, whilst the follow-through phase has been linked to a similar proportion of these injuries [37, 38]. The motion of the trunk during the right-handed golf swing has been described as a combination of right-side lateral flexion and counter-clockwise axial rotation during the downswing [34]. Both of these factors increase rapidly during the downswing and early follow through, reaching their maximum shortly after ball impact [34]. Based on this knowledge, Sugaya and co-workers [39] proposed the use of a unique kinematic variable dubbed the crunch factor to objectively measure and compare the mechanics of the lumbar spine in healthy and pathological golf swings.

The crunch factor was intuitively devised based on the hypothesis that lateral flexion angle and axial trunk rotation both contribute to degenerative changes and injuries in the lumbar spine. This notion has been supported by other research, which has stated that the forceful lateral displacement of the hips combined with rapid hip rotation and trunk hyper-extension are some of the most prominent causes of LBP in modern golf [34, 40-42]. Despite this link, Gluck and co-workers [43] suggest that the clinical relevance of the crunch factor is controversial, due to the lack of empirical evidence to support its use. To date, the authors are only aware of two studies that have reported calculating the crunch factor in a population of golfers with LBP [27, 44]. In contrast to the original work of Sugaya and colleagues [39], which calculated the crunch factor for the lumbar spine only, Lindsay and Horton [27] computed a trunk crunch factor, which also included the motion of the thoracic spine. According to Lindsay and Horton [27], the symptomatic golfers produced lower peak trunk crunch factor values than asymptomatic controls (although not significantly so), but their findings were based on a small sample of six golfers with and without LBP. Furthermore, while Tsai and co-workers [44] describe calculating the crunch factor for golfers with LBP,

the authors did not present the data in the final manuscript. As such, there is a clear need to better understand the possible role of the crunch factor in golf-related low back injuries, as this measure has also been suggested to play an important role in low back injuries in fast bowling cricketers [45].

Hence, this research adopted a cross-sectional research design to assess whether golfers with low back pain demonstrate greater peak crunch factor values than asymptomatic players. This information could provide insight into the possible injury mechanisms associated with the development of golf-related low back pain, together with providing some important evidence for the value of the crunch factor as a measure in other similar dynamic contact and impact-related sports.

## **Methods**

### **Participants**

For the purposes of this study, golfers were recruited via advertisements placed in the local newspaper on the noticeboards of public and private golf courses located in close proximity to the site of data collection. Interested participants were encouraged to contact the principal investigator and were screened over the phone to ensure that they; 1) were older than 18 years of age; 2) had been playing golf for at least 12 months; and 3) had a current playing handicap. During this process, participants were also asked about any previous or current injuries that affected their participation and were then excluded if they were suffering from any injury other than LBP. Twelve right-handed male golfers who reported experiencing LBP whilst playing or practicing golf were accepted into the study and asked to complete the Short-Form McGill Pain Questionnaire (SF-MPQ) after their warm-up on the day of testing to establish the severity of their condition [46]. The SF-MPQ incorporates a visual analogue scale (100

mm line), which patients use to rank the intensity of their pain, with ‘no pain’ denoted by a score of 0 and ‘worst possible pain’ represented by a score of 100 [46]. Logically constructed from the Long-Form McGill Pain Questionnaire [46], the SF-MPQ has exhibited test-retest reliability, content validity, construct validity, concurrent criterion validity, and predictive validity within the literature, thus supporting its use in the assessment of clinical pain [46-49]. On the basis of this assessment, all golfers reported a mild or greater level of pain on the visual analogue scale (mean  $38 \pm 14$  mm; range 22 to 62 mm) and, on average, the golfers described their present pain intensity as discomforting (mean  $2.08 \pm 0.67$ ; range 1 to 3). A further fifteen right-handed male golfers responded to the advertisements and reported no current injuries, no prior history of spinal surgery, spinal fracture or spinal deformity and had not experienced any episodes of LBP requiring medical attention in the previous 12 months. These golfers were recruited to form the no low back pain (NLBP) group. All participants provided written informed consent to participate in the investigation and the experimental methodology was approved by the Human Research Ethics Committee at the University.

**Insert Table 1 about here.**

### **Task**

Prior to data collection, the participants were encouraged to partake in their normal warm-up routines, which included stretching and/or the performance of several practice strokes using an iron golf club. Whilst this routine allowed the golfers to prepare for the task as they would in a normal game of golf, it also served to familiarise the golfers with the experimental surroundings. Following their warm-up, the golfers used their own driver (1 wood) and their own ‘natural’ technique to perform twenty tee-shots in the direction of a flag positioned 320

metres away. During the assessment, the participants positioned themselves and the ball approximately in the centre of a two-metre square area (tee-off box), which was clearly defined on the grass with custom-made markers. To ensure that the golfers could perform the task in an uninhibited manner, all data collection for this research was conducted on a designated grassed area at a local practice driving range.

### **Data Collection**

All golfers were asked to wear a singlet and short-length trousers to facilitate the identification (via palpation) of specific anatomical landmarks to serve as reference points during the three-dimensional analysis. Two markers made from reflective adhesive tape were placed on the lateral aspect of the participants' shoes, overlying the fifth metatarsophalangeal joint. Reflective joint markers were also positioned bilaterally over the lateral malleolus of the fibula; lateral condyle of the femur; greater trochanter; temporomandibular joint; lateral border of the acromion; lateral condyle of the humerus; and the ulnar styloid. A further two markers made from reflective tape were adhered to the shaft of the golf club; one just below the grip and one on the head of the driver. To facilitate the reconstruction of the three-dimensional digitised coordinates, a calibration frame measuring 2.2 m × 1.9 m × 1.6 m (Peak Performance Technologies Inc., USA) comprising 24 points of known three-dimensional spatial locations (x, y and z) was filmed in the tee-off box prior to testing.

Three genlocked Panasonic cameras (Matsushita Electric Industrial Company Ltd., JPN) captured each participant's performance of the tee-shot at an effective sampling rate of 50 Hz and with a shutter speed of 1/2000 of a second. Although 50 Hz sampling frequency may be considered insufficient to examine high-speed movements such as the golf swing, it is important to consider that this investigation aimed to evaluate patterns of movement rather

than high frequency components, such as impact. Similar methods have been employed by previous researchers (e.g. [50, 51]) to assess patterns of motion in golf and, as such the use of this equipment was considered to be adequate to meet the requirements of the investigation. Each of the three cameras were positioned at a vertical height of 1.25 m (measured from the camera lens) and at a horizontal distance of 5.63 m from the centre of the tee-off box. Figure 1 depicts the configuration of the video cameras and is comparable to three-dimensional motion analysis approaches used previously to assess the golf swing [50].

**Insert Figure 1 about here.**

### **Data Analysis**

The joint markers for the best three swings for each golfer were digitised using Vicon Motus 9.2.2 (Vicon, Oxford, UK) and three-dimensional kinematic data were derived using the direct linear transformation (DLT) algorithm [52]. The three best trials were identified by the principal researcher and were based upon a qualitative assessment of the shot's accuracy and flight path following ball contact. A quintic spline function [53] was employed to smooth the raw data following coordinate digitisation and data reconstruction, which facilitated the calculation of kinematic quantities. The selection of a spline function was based on the work of Woltring [53] and Challis and Kerwin [54], who suggested that spline functions were more appropriate for processing kinematic data, as they accurately replicate the smooth nature of human movement, whilst eliminating random noise. Sugaya and co-workers [39] defined the lumbar crunch factor (CF) as the instantaneous product of axial angular velocity of the trunk ( $\omega_{\text{trunk axial}}$ ) and the lateral flexion angle of the spine ( $\theta_{\text{trunk flexion}}$ ). [Equation 1]

$$\text{CF} = \omega_{\text{trunk axial}} \times \theta_{\text{trunk flexion}}$$

Equation 1

deg<sup>2</sup>/s                      deg/s                      deg



In the original work by Sugaya et al. [39] the crunch factor was calculated by the multiplication of these variables, as they each clearly represented a particular potential injurious component that is present around impact. However, the authors feel that it may be important to point out that the determination of the crunch factor by this method does not appear to have any other rationale and does not seem to have been proposed based on any well-researched criteria. For the purposes of this study, the axial angular trunk velocity was calculated as the change in hip to trunk differential angle over a designated time increment. The hip angle was considered to be the angle formed between the line joining the hip joint centres and a theoretical line parallel to the y-axis between the tee and the target (Transverse plane). Similarly, the trunk angle was calculated as the angle formed between this theoretical line and the line between two virtual markers located bilaterally midway between the hip and the shoulder joint markers (Figure 2). For both the hip and trunk angles, a positive value was indicative of rotation from the neutral position away from the target (closed position; clockwise rotation), whilst rotation from the neutral position towards the target (open position; counter-clockwise rotation) was represented by a negative value. The lateral flexion angle of the spine required two virtual points to be calculated based on the location of the hip and shoulder markers. The mid-hip virtual point was calculated as the half distance between the left and right hip markers, whilst the mid-shoulder virtual point was calculated in a similar fashion for the left and right shoulder markers. The lateral flexion angle of the spine was subsequently calculated as the angle formed between the line that joined the mid-hip and mid-shoulder points and the right and left hip markers minus ninety degrees (Figure 3).

**Insert Figures 2 and 3 about here.**

## Statistical Analysis

To assess for any differences between the two groups with respect to the peak crunch factor and the kinematic variables that constituted this measure, a one-way analysis of variance (ANOVA) was conducted using PASW Statistics v18.0. To account for the small sample sizes of the groups, a conservative level of significance was employed ( $p \leq 0.01$ ). Additionally, Cohen's  $d$  effect sizes were calculated to provide insight into the degree to which the independent and dependent variables were related [55]. In accordance with the tentative recommendations of Cohen [55], an effect size of less than 0.2 was considered to be a negligible effect, whilst an effect size of between 0.2 and 0.5 was classified as small. Similarly, effect sizes of between 0.5 and 0.8 were deemed to be indicative of a medium effect, whilst a value greater than 0.8 was representative of a large effect size. Effect sizes assess the degree of association that exists between the independent (IV) and dependent variables (DV) and determine what proportion of the total variance in the DVs (e.g. maximum crunch factor) can be estimated by knowledge of the levels of the IVs [56].

## Results

The average crunch factor graphs for the LBP (Figure 4) and NLBP groups (Figure 5) illustrate a marked increase in this variable from the mid-point of the downswing through impact and into the early follow-through. The average ( $\pm$  SEM) peak crunch factor value for the LBP golfers ( $4879.7 \pm 633.6 \text{ deg}^2/\text{sec}$ ) was not significantly different to the mean value observed for the NLBP ( $4920.2 \pm 587.0 \text{ deg}^2/\text{sec}$ ) group ( $p = 0.96$ ;  $d = 0.02$ ). Interestingly, for those golfers who produced higher crunch factor values (irrespective of group), the increased magnitude could not be attributed entirely to an increased axial angular trunk velocity or lateral flexion angle, but rather to a concomitant increase in both of these variables. The results of the one-way ANOVA demonstrated that the timing of peak crunch

factor was not significantly different for the LBP (14.4% into the follow-through) and NLBP (12.1% into the follow-through) golfers ( $p = 0.16$ ;  $d = 0.55$ ).

**Insert Figures 4 and 5 about here.**

With respect to the lateral flexion angle and the axial angular trunk velocity (Table 2), the results of the statistical analysis showed no significant differences between the LBP and NLBP golfers at address, top of the backswing (TBS), impact, or at the time that maximum crunch factor occurred. Similarly, the LBP and NLBP golfers demonstrated very similar patterns of hip and trunk rotation throughout the golf swing (Table 2). However, although not statistically significant (Table 3), the results of this investigation tended to suggest that the NLBP golfers achieved a greater hip to trunk separation angle at TBS, when compared with the LBP group ( $p = 0.07$ ;  $d = 0.77$ ).

**Insert Tables 2 and 3 about here.**

## **Discussion and Implications**

Although it has been suggested that the magnitude of the lateral flexion angle and axial rotational velocity may play a significant role in vertebral degeneration and spinal injuries in golfers, this research demonstrated that both of these variables and the subsequent crunch factor did not differ significantly between golfers with and without low back pain. Similar findings were reported previously by Lindsay and Horton [27], who reported no significant differences in the peak crunch factor of six symptomatic professional golfers and six asymptomatic controls. The magnitude of the average peak crunch factor values ( $\pm 1SD$ ) reported by Lindsay and Horton [27] for their symptomatic ( $4720.2 \pm 1253.9 \text{ deg}^2/\text{sec}$ ) and

asymptomatic golfers ( $5026.3 \pm 1627.6 \text{ deg}^2/\text{sec}$ ) were similar to those findings presented for this study (LBP =  $4879.7 \pm 2194.9 \text{ deg}^2/\text{sec}$ ; NLBP =  $4920.2 \pm 2273.4 \text{ deg}^2/\text{sec}$ ). However, the findings of the current study tended to be greater than those presented by Morgan *et al.* [57] for a group of healthy collegiate ( $2586 \pm 1245 \text{ deg}^2/\text{sec}$ ), recreational ( $1519 \pm 986 \text{ deg}^2/\text{sec}$ ) and senior golfers ( $1270 \pm 935 \text{ deg}^2/\text{sec}$ ).

With respect to the two kinematic components that comprise the crunch factor, it was interesting to note that the mean peak lateral flexion angles for the LBP ( $-19.1 \pm 5.6^\circ$ ) and NLBP golfers ( $-19.1 \pm 5.7^\circ$ ) were comparable to those presented by Morgan and co-workers [57] for their three population groups. However, the data presented by Lindsay and Horton [27] showed peak right-side flexion angles that were more than 50% greater than those reported by Morgan and co-workers [57] and those presented in the current investigation. A possible explanation for this discrepancy is the difference in methodologies used, as Morgan and colleagues [57] and the current investigation both used three-dimensional motion analysis to assess trunk motion, whilst Lindsay and Horton [27] employed a tri-axial electrogoniometer (Lumbar Motion Monitor). In contrast to these results, the average maximum axial angular velocities of the trunk for the LBP ( $-271.0 \pm 76.8 \text{ deg/sec}$ ) and NLBP groups ( $-260.4 \pm 50.3 \text{ deg/sec}$ ) in the current study tended to be higher than those reported by Morgan and colleagues [57] and Lindsay and Horton [27]. In their study, Morgan and co-workers [57] reported peak axial angular trunk velocities of  $202 (\pm 19)$ ,  $143 (\pm 44)$  and  $114 (\pm 50) \text{ deg/sec}$  for their college, adult and senior golfing groups, whilst Lindsay and Horton [27] recorded maximum values of  $186.1 (\pm 33.4)$  and  $182.4 (\pm 92.6) \text{ deg/sec}$  for their symptomatic and asymptomatic golfers, respectively.

The lack of a significant finding between the two groups in the current study is important, as it has previously and recently been postulated that axial trunk rotational velocity and lateral flexion angle of the spine may be important in the development of low back injuries [14, 34, 45, 57]. However, while the crunch factor does not appear to be a sensitive measure for distinguishing golfers with LBP from asymptomatic players, the complex movement pattern that it represents may be a contributory factor to overuse injuries. Firstly, it is interesting to note that the occurrence of peak crunch factor values during the early stages of the follow-through coincides with the peak anteroposterior and lateral bending forces presented in previous research [35]. When we consider that the golf swing puts considerable stress on the intervertebral discs, which are poorly designed to attenuate shear forces [15, 58, 59] and that golfers with LBP have altered trunk muscle activity patterns [60, 61], it may be reasonable to suggest that golfers with LBP have a reduced capacity to cope with the demands of the movement.

Nonetheless, it is important to consider that a potential limitation of the crunch factor is that its calculation gives equal weighting to both of the components that comprise it. This issue was briefly discussed in a review of the possible role of the crunch factor in the development of low back injuries in cricket fast bowlers, where the author proposed that the instantaneous product of axial angular trunk velocity and lateral flexion velocity (i.e. not angle) might be more suitable for identifying risk of injury in cricketers [45]. However, this proposal was based on the authors interpretation of ensemble averages presented by Ferdinands et al. [62], so additional work would be required to determine the value of this or similar variants to the crunch factor. Furthermore, while the LBP and NLBP golfers in the current study demonstrated similar crunch factors during the performance of the full golf swing using a driver, potentially injurious differences may exist in this variable whilst using the shorter

clubs (e.g. irons). Research has demonstrated that kinematic profiles differ significantly between the driver and irons, indicating that the shorter clubs tend to place less emphasis on trunk rotation and more emphasis on lateral trunk motion and right-side flexion velocity [63, 64]. For this reason, future research may seek to establish the potential influence of the crunch factor in the development of LBP during the performance of a full golf swing using an iron.

As with any research investigation of this nature, there were limitations that should be acknowledged and considered by the reader when interpreting these findings. Firstly, the calculation of the hip and mid-trunk angles using lines joining the hip and shoulder joint centres may have been subject to some error. For example, joint anatomical locations that create the lines are essentially unfixed and can be influenced by other factors. Secondly, the size of the LBP and NLBP sample populations was small (from a statistical standpoint) and for this reason, it is recommended that the reader consider the effect sizes that are reported and support the conclusions. Thirdly, although similar methods of data reduction have been used in previous studies [65-68], it is possible that by analysing the best performances for each golfer that an element of bias was introduced, as characteristics of performance variability may not have been adequately represented. Finally, given the lack of any significantly different findings between the groups, it is important to recognise that the LBP golfers had a history of golf-related low back pain at the time of testing. Therefore, it remains feasible to suggest that higher peak crunch factor values may be evident in the LBP golfers pre-injury and possibly decrease following the onset of symptoms. However, to effectively address this important issue, a well-devised longitudinal investigation would be necessary; however this was beyond the scope of this investigation.

## **Conclusion**

The results of this research indicated that golfers with and without LBP did not demonstrate significantly different lumbar crunch factor values throughout the performance of a tee-shot. It is important to identify that while the fundamental concept that underpins the crunch factor seems logical and, indeed, may be applicable to other sports involving large changes in spinal angles and rapid trunk rotation (e.g. cricket, javelin), the validity of this measure has not been determined in previous or current research. The presented findings suggest that the crunch factor does not differ significantly between players with and without golf-related LBP, but it remains unclear as to whether the crunch factor profile observed in these golfers is comparable to that which they demonstrated prior to their injury. Consequently, it is suggested that future research aims to assess the crunch factor longitudinally in the asymptomatic population to determine whether those who develop low back pain have an increased peak crunch factor pre-injury and/or an altered neuromuscular recruitment pattern.

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Tables

**Table 1:** The average age, height, mass, body mass index (BMI) and handicap of the low back pain (LBP) and no low back pain (NLBP) golfer groups.

| Low Back Pain Golfers |           |            |           |                          |          | No Low Back Pain Golfers |            |           |                          |          |
|-----------------------|-----------|------------|-----------|--------------------------|----------|--------------------------|------------|-----------|--------------------------|----------|
| (n = 12 golfers)      |           |            |           |                          |          | (n = 15 golfers)         |            |           |                          |          |
|                       | Age (yrs) | Height (m) | Mass (kg) | BMI (kg/m <sup>2</sup> ) | Handicap | Age (yrs)                | Height (m) | Mass (kg) | BMI (kg/m <sup>2</sup> ) | Handicap |
| Mean                  | 46.00     | 1.85*      | 84.00     | 24.77                    | 10.50    | 39.60                    | 1.77*      | 82.73     | 26.48                    | 10.40    |
| SEM                   | 5.15      | 0.03       | 1.52      | 0.71                     | 2.43     | 3.60                     | 0.01       | 1.49      | 0.64                     | 1.07     |

*Note:* \* indicates a significant difference ( $p < 0.05$ ) between the groups.

**Table 2:** The mean (and SEM) angular trunk kinematics measured for the low back pain (LBP) and no low back pain (NLBP) golfers at address, at the top of the backswing (TBS), at impact and at the time that peak crunch factor was achieved.

|                               |                     |      | Low Back Pain Golfers |            |               |                   | No Low Back Pain Golfers |            |               |                   |
|-------------------------------|---------------------|------|-----------------------|------------|---------------|-------------------|--------------------------|------------|---------------|-------------------|
|                               |                     |      | <u>Address</u>        | <u>TBS</u> | <u>Impact</u> | <u>At Peak CF</u> | <u>Address</u>           | <u>TBS</u> | <u>Impact</u> | <u>At Peak CF</u> |
| Lateral Flexion               | deg                 | Mean | -2.2                  | 1.4        | -18.2         | -18.1             | -1.3                     | 3.5        | -16.8         | -18.5             |
|                               |                     | SEM  | 0.6                   | 1.7        | 1.7           | 1.5               | 1.0                      | 1.0        | 1.4           | 1.5               |
| Trunk Angle                   | deg                 | Mean | -3.2                  | 58.7       | -20.4         | -43.9             | -5.6                     | 64.5       | -20.8         | -40.2             |
|                               |                     | SEM  | 1.2                   | 3.2        | 2.2           | 3.7               | 0.7                      | 2.0        | 2.4           | 3.3               |
| Hip Angle                     | deg                 | Mean | -0.7                  | 33.8       | -28.6         | -40.7             | -2.0                     | 35.5       | -29.1         | -39.1             |
|                               |                     | SEM  | 1.1                   | 2.5        | 2.8           | 3.6               | 0.8                      | 3.0        | 3.2           | 3.5               |
| Hip to Trunk Separation Angle | deg                 | Mean | -2.5                  | 24.8       | 8.1           | -3.2              | -3.6                     | 29.0       | 8.3           | -1.1              |
|                               |                     | SEM  | 0.6                   | 1.2        | 1.2           | 1.1               | 0.7                      | 1.7        | 1.3           | 1.4               |
| Axial Angular Trunk Velocity  | deg/s               | Mean | 5.3                   | 11.2       | -183.4        | -266.4            | 5.7                      | 11.5       | -209.0        | -256.8            |
|                               |                     | SEM  | 1.3                   | 6.7        | 20.5          | 21.9              | 1.9                      | 8.0        | 11.5          | 13.5              |
| Crunch Factor                 | deg <sup>2</sup> /s | Mean | -12.4                 | 30.3       | 3412.3        | 4879.7            | -7.5                     | 20.1       | 3601.2        | 4920.2            |
|                               |                     | SEM  | 5.7                   | 51.8       | 477.2         | 633.6             | 9.0                      | 39.0       | 362.2         | 587.0             |



**Table 3:** The results of the statistical analysis (*p*- and *d*-values) of the trunk kinematics recorded for the low back pain (LBP) and no low back pain (NLBP) golfers during the different phases of the golf swing.

| Statistical Results and Effect Size Estimates |                 |          |             |          |             |          |                         |          |                              |          |               |          |
|---|-----------------|----------|-------------|----------|-------------|----------|-------------------------|----------|------------------------------|----------|---------------|----------|
|   | Lateral Flexion |          | Trunk Angle |          | Hip Angle   |          | Hip to Trunk Separation |          | Axial Angular Trunk Velocity |          | Crunch Factor |          |
|   | <i>p</i>        | <i>d</i> | <i>p</i>    | <i>d</i> | <i>p</i>    | <i>d</i> | <i>p</i>                | <i>d</i> | <i>p</i>                     | <i>d</i> | <i>p</i>      | <i>d</i> |
| Address                                       | <b>0.50</b>     | 0.27     | <b>0.08</b> | 0.74     | <b>0.32</b> | 0.41     | <b>0.24</b>             | 0.48     | <b>0.87</b>                  | 0.07     | <b>0.67</b>   | 0.17     |
| TBS   | <b>0.28</b>     | 0.44     | <b>0.12</b> | 0.65     | <b>0.68</b> | 0.17     | <b>0.07</b>             | 0.77     | <b>0.98</b>                  | 0.01     | <b>0.87</b>   | 0.06     |
| Impact  | <b>0.51</b>     | 0.27     | <b>0.92</b> | 0.04     | <b>0.91</b> | 0.05     | <b>0.93</b>             | 0.04     | <b>0.26</b>                  | 0.46     | <b>0.75</b>   | 0.12     |
| At Peak CF                                    | <b>0.86</b>     | 0.07     | <b>0.46</b> | 0.31     | <b>0.75</b> | 0.13     | <b>0.27</b>             | 0.45     | <b>0.70</b>                  | 0.16     | <b>0.96</b>   | 0.02     |

## **Figure Legends**

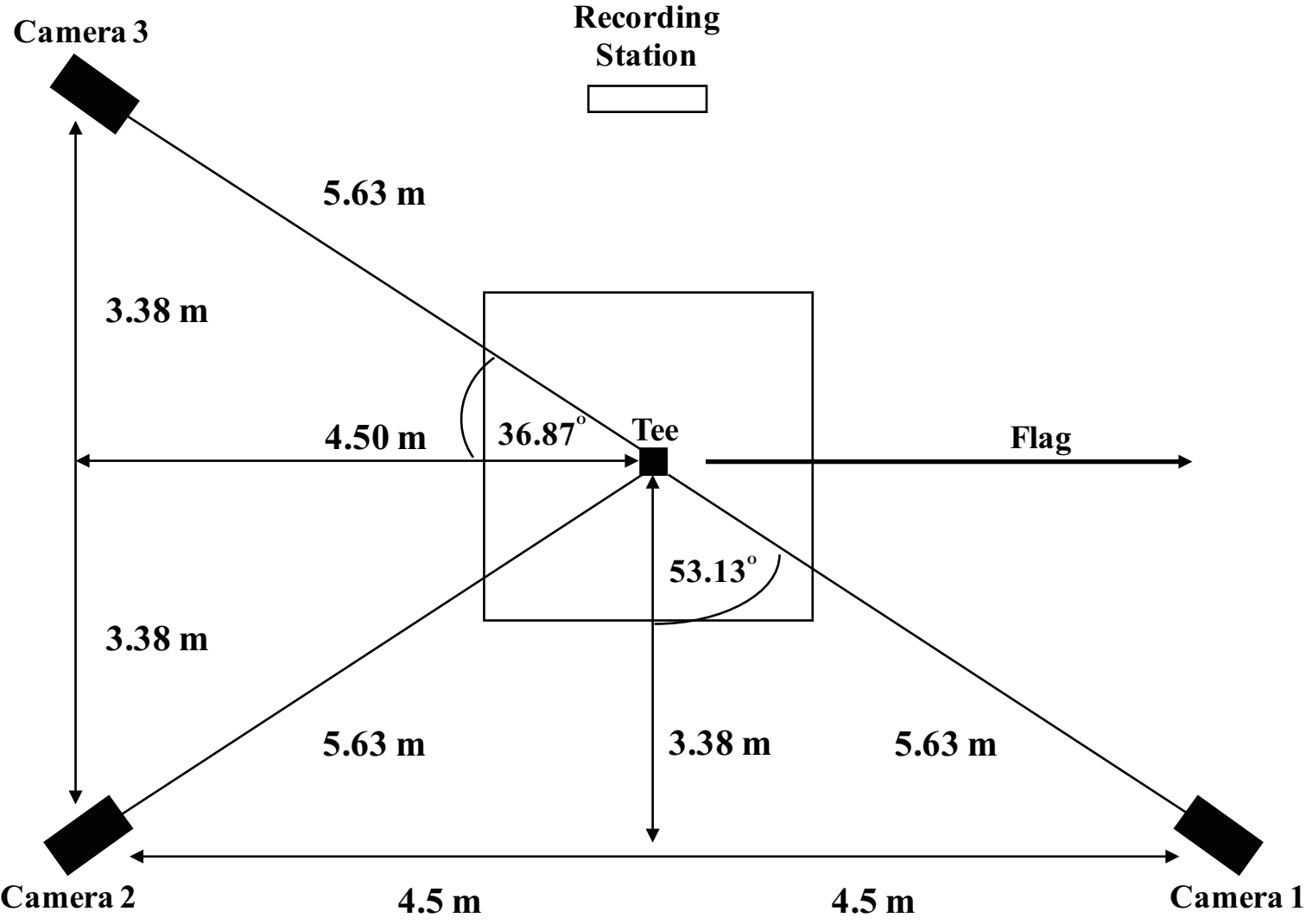
**Figure 1:** The layout of the three-dimensional motion analysis equipment.

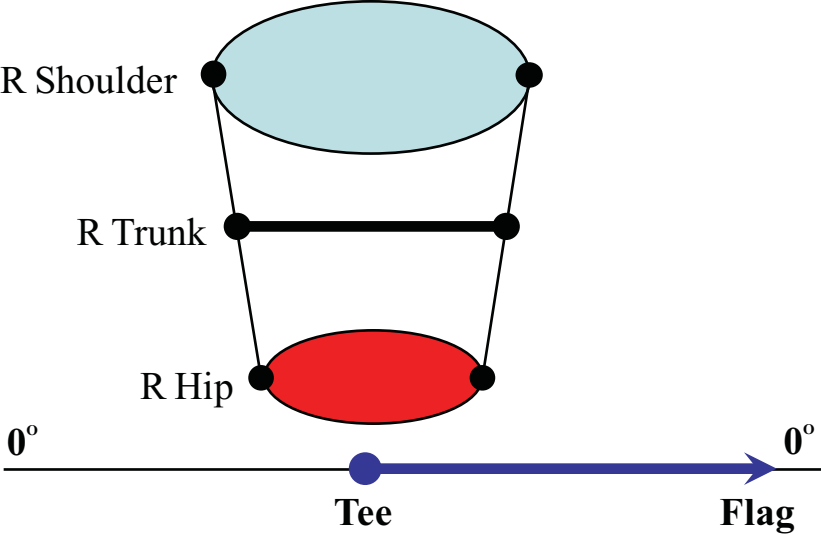
**Figure 2:** The defined trunk segment and the resulting trunk angle as viewed from the oblique frontal and transverse planes.

**Figure 3:** The method of calculation for the lateral flexion angle of the trunk.

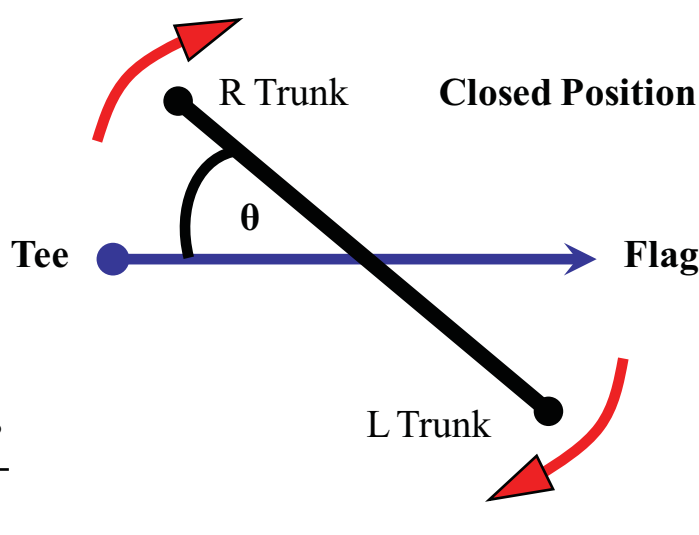
**Figure 4:** The mean ( $\pm 1$  SEM) crunch factor recorded throughout the swing for the LBP golfers. The event lines on the graph identify the top of the backswing and the point of impact between the ball and club head.

**Figure 5:** The average ( $\pm 1$  SEM) crunch factor recorded for the NLBP golfers during the golf swing. The plotted event lines denote the top of the backswing and the point of impact between the ball and club head.

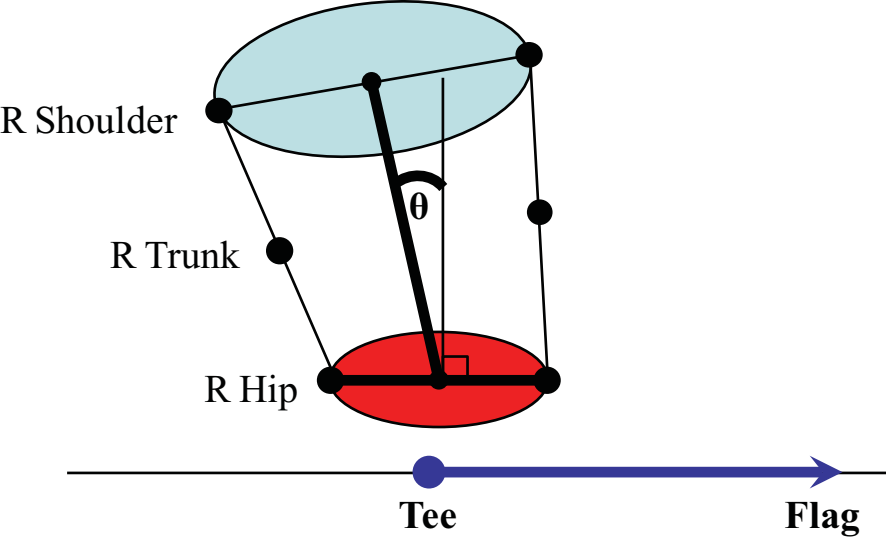




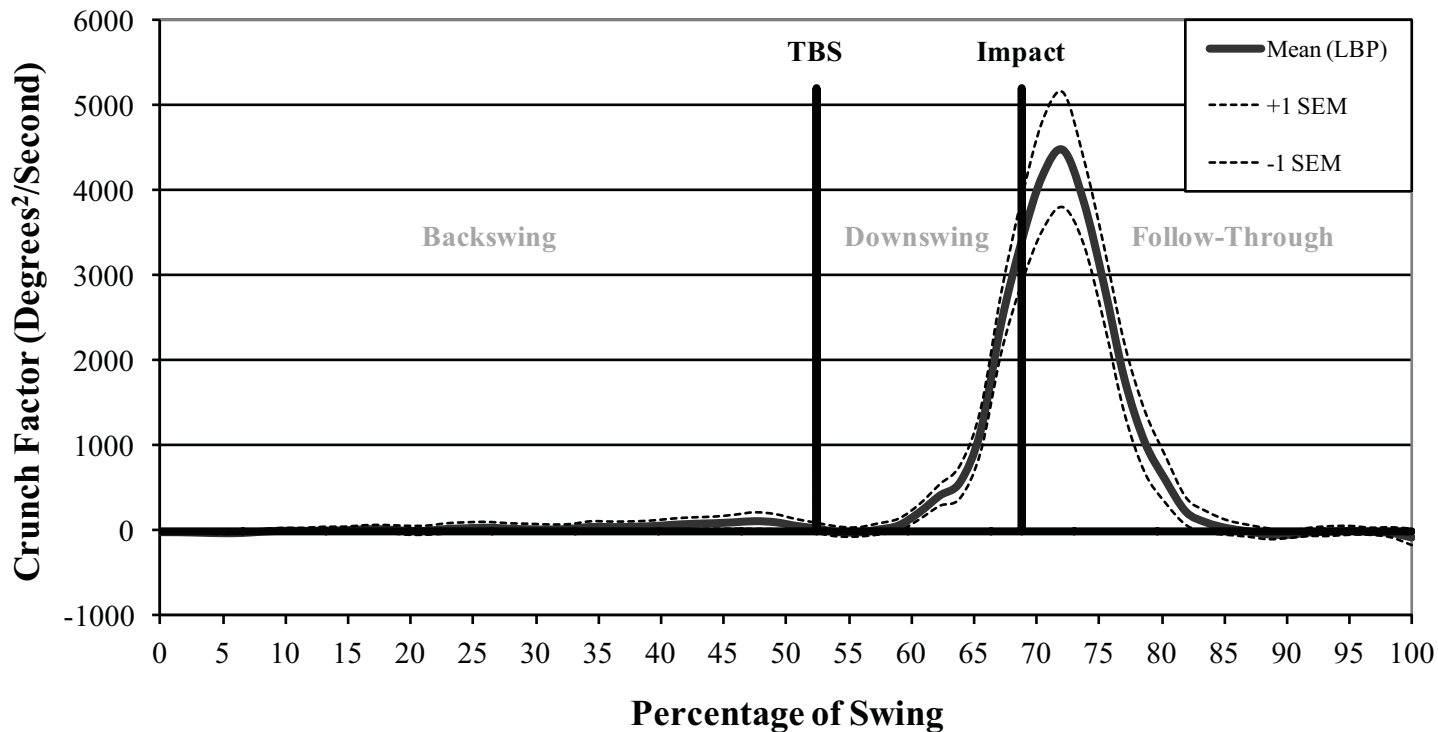
Frontal View



Transverse View



# Average Crunch Factor Low Back Pain (LBP) Golfers



# Average Crunch Factor No Low Back Pain (NLBP) Golfers

